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Multiple 3D reference system analyses for Phobos grooves, a novel approach

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Grooves analysis has represented in the last decade a robust method for geomorphological study of small bodies, as is the case for asteroids 951 Gaspra (Veverka et al., 1994), 243 Ida (Belton et al., 1994), 433 Eros (Thomas et al., (2002), Buczkowski et al., 2008), 21 Lutetia (Massironi et al., 2011, *Besse et al., 2014*) and 4 Vesta (Buczkowski et al., 2*012). Hence, such source of information can be deeper used for a novel approach presented on Phobos with the aim of providing more hints on its harshly debated origin.

Stereo-plots and cyclographs represent two methods, unified under the name of stereographic projections, commonly used to describe the statistic of the orientations (dip-angle and dip-direction) of different planes with respect to cardinal points and a reference horizontal plane (Bucher, 1944; Phillips, 1954; Ragan, 1985). However this reference system is ambiguous for any applications on small irregular bodies such as asteroids or comets since it does not permit to highlight systems of parallel anisotropies and to have an idea of their distribution with respect to a given surface feature (for example an impact crater).

In this work we show a novel approach for stereographic projections focusing to a multi-reference system. The multi-reference system can be centered on a specific surface feature such as a crater and can alternatively use an absolute reference plane containing the center of figure of the body (to retrieve systems of parallel anisotropies) or a relative horizontal plane (to understand the distribution of the anisotropies with respect to the central feature). In this way we are able to well define the distribution of the grooves expected to be originated from a impact cratering event in a small body.

Following this methodology, we have extracted 352 3D fracture planes from the attitudes of the grooves over the surface topography of Phobos and, for each plane, the local surface versor has been defined. Consequently, stereo-plots on absolute and relative reference systems have been retrieved to recognize the mutual orientation of the different joint sets and their relationship with respect to specific regions where major impacts were recorded.

Assuming that grooves could be expression of fracture and joints and by retrieving planes and related stereo plots from the linear features at the surface, we recognized that only a minimum percentage with respect to the total amount of grooves is related to major craters. On the other hand two main cross-cutting parallel sets, unrelated to any crater, have been found. This observation allowed us to propose a new formation scenario for Phobos grooves which has important consequences on the origin of Phobos itself: a single shard formation from an ancient fractured parent body.

Such scenario has never been taken into consideration for Phobos and has two major consequences: one side the observed grooves distribution could be explained as the result of possible major impacts on the larger parent body, which were inherited by the "Phobos shard", while on the other side could hint towards an ancient asteroidal origin of this satellite.